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# Deep transitions: Emergence, acceleration, stabilization and directionality

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ABSTRACT

Industrial society has not only led to high levels of wealth and welfare in the Western world, but also to increasing global ecological degradation and social inequality. The socio-technical systems that underlay contemporary societies have substantially contributed to these outcomes. This paper proposes that these socio-technical systems are an expression of a limited number of meta-rules that, for the past 250 years, have driven innovation and hence system evolution in a particular direction, thereby constituting the First Deep Transition. Meeting the cumulative social and ecological consequences of the overall direction of the First Deep Transition would require a radical change, not only in socio-technical systems but also in the meta-rules driving their evolution – the Second Deep Transition. This paper develops a new theoretical framework that aims to explain the emergence, acceleration, stabilization and directionality of Deep Transitions. It does so through the synthesis of two literatures that have attempted to explain large-scale and long-term socio-technical change: the Multi-level Perspective (MLP) on socio-technical transitions, and Techno-economic Paradigm (TEP) framework.

## 1. Introduction

Recently (2015), the United Nations formulated 17 Sustainable Development Goals, calling for revolutionary greener production, increased social justice, a fairer distribution of welfare, sustainable consumption patterns, and new ways of producing economic growth. Others are promoting "smart, sustainable and inclusive growth" (European Commission, 2010), "a circular economy" (European Environment Agency, 2016), or "a social contract for sustainability" (WGBU, 2011). However, it remains an open question how these goals are to be achieved, especially in the context of the current double challenge of environmental degradation (IPCC, 2014; Steffen et al., 2015) and social inequality (Piketty, 2014; Milanovic, 2016).

Drawing on much work in the sustainability transitions field, we start from the assumption that in order to respond to these interconnected social, economic and ecological challenges, fundamental changes are necessary in a wide range of socio-technical systems for the provision of energy, mobility, food, housing, communication, water, healthcare, education, finance, etc. These systems encompass production, distribution and consumption, and should thus not be confused with sectors. They can be defined as configurations of actors, technologies and institutions for the fulfilment of societal functions that form the material backbone of modern civilization. In this paper we develop a Deep Transition (Schot, 2016) framework for understanding how changes across multiple systems became connected and coordinated, developing a common directionality in the long run. We thus devote this paper to exploring the following broad research question: how can we understand the emergence, acceleration, stabilization and directionality of Deep Transitions?

A Deep Transition is formally defined as a series of connected and sustained fundamental transformations of a wide range of socio-technical systems in a similar direction. Examples of this directionality[1] include a move towards increased labour productivity, mechanization, reliance on fossil fuels, resource-intensity, energy-intensity, and reliance on global value chains. Our assumption is that this process of building connections between change processes in multiple systems takes on wave-type properties, unfolds through centuries, and is implicated in broader transformations of societies and economies. In this conceptualization each wave is broadening and deepening the Deep Transition, but should not be seen as a Deep Transition in itself. The Deep Transition refers to the overall change process, and is thus comparable to what Polanyi (2001 [1944]) called the Great Transformation. Others have analysed this as the process of industrialization (Mokyr, 1990; McNeill and McNeill, 2003; McClellan and Dorn, 2015), or as the

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[1] The notion of directionality was introduced by Stirling (2008, 2009) as part of his call for opening up the process of technical change for alternative options. He builds on the broader idea that socio-technical change has a direction, choices are made between directions and actors gradually become blind to alternatives, which is a central tenet of much of the innovation studies literature. Our notion of directionality also draws on this idea (see also Weber and Rohracher, 2012: 1042–1043).

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emergence of a distinctive socio-metabolic profile of industrial societies (Fischer-Kowalski and Haberl, 2007; Swilling, 2013; Haberl et al., 2017). What makes the Deep Transitions approach distinctive is its emphasis on socio-technical (vs. 'natural' and/or 'social') systems, its attention to the parallel evolution of single systems, complexes of systems as well as the broader and long term transformations of industrial society as a whole, and the role of rule-systems (called regimes and meta-regimes) in driving the directionality of the entire process.

We call the build-up of various socio-technical systems in waves, taking place over the 19th and 20th centuries, the First Deep Transition.[2] On one hand, the historical expansion and globalization of this First Deep Transition led to unprecedented levels of wealth and welfare in the Western world. However, on the other hand the whole process was marred with recurrent problems such as climate change (caused by the use of fossil fuels), pollution, an enormous waste of resources (caused by the assumptions of limitless supply of resources and limitless capacity to absorb waste), inequality (caused by system innovation mainly aimed at the richer markets) and persistent unemployment (caused by a relentless emphasis on productivity growth). As these harmful outcomes occurred, re-occurred, cumulated and amplified, serious worries started to be expressed about the sustainability of this path (Meadows et al., 1972; Brown, 1984). It became clear that the challenge of sustainability requires a fundamental change of production, distribution and consumption patterns.

Recently these concerns have created increasing pressures on existing socio-technical systems, thereby stimulating possibilities for the emergence of the Second Deep Transition: an overhaul of the directionality of the First Deep Transition and therefore the most fundamental principles guiding the mode of operation of socio-technical systems constituting modern societies. We suggest that this sea-change has gradually started to unfold since the 1970s in specific niches, not as a mainstream development but rather as an undercurrent of historical change. Examples include renewable energy development, alternative food production practices, emergence of new types of mobility services, and many others. In this paper we seek to undertake a first step towards identifying and theorizing the significance of these niches in the context of long term transition processes.

While our overall ambition is to create a new theoretical framework conceptualizing the co-evolution of single socio-technical systems, interconnected systems and industrial modernity as a whole, in this paper we focus on the first piece of the puzzle: understanding the relationships between shifts in single and interconnected systems. The long term patterns that formatted industrial modernity, and were generated by the build-up of these connections, will be discussed in a follow-up paper. For the conceptualization of the development of connected systems in the long term, we draw on two well-established, empirically supported and complementary approaches: the Techno-economic Paradigm theory (TEP) and the Multi-level Perspective on socio-technical transitions (MLP). Section 2 provides a critical overview of both, paving the way for a synthesis in Section 3, where we present the Deep Transition framework. Section 4 provides a final discussion, outlining a research strategy and indicating the need for further conceptual work.

## 2. Theorizing deep transitions

The notion of Deep Transitions developed here entails a focus on large-scale and long-term socio-technical systems change. Existing literature on the topic often operates on the level of individual socio-technical systems. It analyses how socio-technical systems emerge, grow, mature and decline, and how shifts from one system to another take place. Examples of such approaches are Large Technical Systems theory (Hughes, 1983; Nye, 1998), the Technological Innovation System approach (Carlsson and Stankiewicz, 1991; Bergek et al., 2008, 2015), and the Multi-level Perspective (MLP) on socio-technical transitions (Geels, 2005a; Grin et al., 2010). The analysis of the long term development of a set of interrelated multiple socio-technical systems and the environment in which these systems reside has received somewhat less attention in comparison: relevant approaches include the Control Revolution thesis (Beniger, 1986), Eras of Technology concept (Misa, 2004), and the Techno-economic Paradigm (TEP) framework (Freeman and Louçã, 2001; Perez, 2002). What is largely missing from current literature, however, is how individual socio-technical systems have historically become connected into complexes of systems, developed traction in particular directions, and how these complexes, in turn, have increasingly become part of the socio-material fabric of our economies, polities, cultural frameworks, social interactions and everyday practices.

We have chosen to address this gap by integrating MLP and TEP in a new Deep Transition framework. Admittedly, taken together TEP and MLP is not the only combination possible, but we believe that it provides a promising and powerful starting point for understanding Deep Transitions. Both draw together the insights of various disciplines such as sociology, economic history or institutionalism; at the same time, both are based on evolutionary theory, making their ontological foundations compatible. Perhaps more importantly, the synthesis allows the conceptualization of the endogenous and co-evolutionary change of individual and multiple systems, the build-up of a long-term change process in a wave-like pattern, and the overall directionality of this process. Finally, both frameworks are underpinned by substantial empirical research and they are conceptually complementary, providing remedies for each other's shortcomings.

### 2.1. Techno-economic paradigm framework

The Techno-economic Paradigm framework (TEP) (Perez, 1983; Freeman and Perez, 1988; Tylecote, 1992; Podobnik, 1999; Freeman and Louçã, 2001; Perez, 2002; Dewick et al., 2004; Drechsler et al., 2009; Mathews, 2013, 2014) has generally focused on explaining long waves: 40–60 year long cyclical variations in economic growth. What it brings to the Deep Transition framework is the idea that the First Deep Transition emerged through a set of distinctive waves. Various mechanisms have been assumed to be responsible for creating these historical wave-like patterns, including the availability of credit, fluctuations in the production of gold, the emergence of new states and demographic changes (see Papenhausen, 2008: 790–793; Köhler, 2012: 3; Bernard et al., 2014: 89, for partly overlapping lists of causes). What makes TEP distinctive is its stress on clusters of interrelated technological, organizational and institutional innovations as drivers of these waves. It is argued that, historically, these clusters have led to major increases in productivity and product quality, structural changes in production and consumption, and long-term economic growth, as well as major political and cultural impacts (Freeman and Louçã, 2001; Perez, 2002). Each wave evolves from small beginnings in certain sectors and/or regional areas and ends up encompassing the entire economies and societies of leading countries, gradually diffusing to other countries as well. Since the beginning of the Industrial Revolution, there have been five such waves.

Perez (2002), who prefers to speak about Great Surges of Development instead of long waves, identifies the key components of these transformations. She suggests that each surge has consisted of an important all-pervasive low-cost input, often a source of energy (e.g. coal or oil) or a new material (e.g. plastics), new technologies, products and processes, and new or fundamentally redefined infrastructures (Perez, 2010). However, the transformative power of the surge is not located in

[2] We have chosen this particular numbering because the conceptualization we put forward does not apply to pre-modern societies. It is rooted in the build-up of a set of socio-technical systems that did not exist before; their rise to dominance in fact characterizes the genesis of the First Deep Transition. We are aware, however, that from different perspectives, such as the energy and material usage profile, a good case can be made that the agrarian shift was of similar historical significance (see Fischer-Kowalski and Haberl, 2007; Haberl et al., 2017, for more detail).

the mere presence and interconnectedness of these elements. The transformation only takes off once they are combined with an appropriate techno-economic paradigm (Perez, 1983, 1985), i.e.:

> "…a best practice model made up of a set of all pervasive generic technological and organizational principles, which represents the most effective way of applying a particular technological revolution and using it for modernizing and rejuvenating the whole of the economy. When generally adopted, these principles become the common-sense basis for organizing any activity and for structuring any institution." (Perez, 2002: 17)

In other words, techno-economic paradigms provide what we will call a meta-regime: a coordinating mechanism generating interconnections between technologies and industries.[3] Table 1 provides a descriptive overview of the main characteristics of all five surges.

The early version of long wave literature, including TEP, was accused of being unable to provide convincing statistical evidence for the existence of waves in aggregate indicators such as wholesale price levels or GDP (see Freeman and Louçã, 2001: 9–135; De Groot and Franses, 2012; Bernard et al., 2014). Additional criticism included the tendency towards technological determinism and a lack of agency (see Geels, 2005a: 68–72; Köhler, 2012; Lachman, 2013, for summaries of these arguments). Responses to these issues have included the use of alternative techniques and data sources for detecting the waves (Korotayev and Tsirel, 2010; Korotayev et al., 2011; Gallegati, 2017), attempts to re-interpret historical and current events as asynchronous intersections of the phases of different cycles (e.g. Gore, 2010; Swilling, 2013; Tyfield, 2016), extended conceptual work turning attention to the combination of scientific, technological, economic, political and cultural preconditions of long waves (Freeman and Louçã, 2001: 124–130), and the turn away from aggregate statistics and quantitative measurement towards qualitative interpretation of historical data (Freeman and Louçã, 2001; Perez, 2002). In an influential theoretical reformulation, Perez (2002) sought to explain the diffusion of technological revolutions in terms of the actions undertaken by the agents of financial capital, production capital[4] and the state. This shift in explanatory focus from economic aggregates to the dynamics of interconnected socio-technical systems, as well as explicit incorporation of agency, makes the Perezian version the strongest answer to the above criticisms to date, and therefore a promising building block for the theory of Deep Transitions. For these reasons we will discuss her theory in detail below.

Perez (2002) proposes that the dynamics of Great Surges of Development stem from two sources: first, the saturation of specific technological opportunities within the framework of an existing paradigm. In other words, over time the combination of technological revolutions underlying each surge and their best practices of application run into diminishing returns. The second source results from the difference in ease with which the agents of production and financial capital are able to reorient themselves. Whereas the former are tied to the existing equipment, buildings, knowledge, experience, organization, personnel, external networks of suppliers, distributors and clients, the latter are more flexible and mobile. Thus, when the existing industries run into problems, the agents of financial capital are able relocate their investments quicker.

Perez (2002, 2011) divides the evolution of surges into two periods separated by a turning point: installation period (further divided into irruption and frenzy phases) and deployment (further divided into synergy and maturity phases) (see Fig. 1). The emergence of each new surge overlaps with the decline of the dominant one. In the irruption phase, the old surge starts to exhaust itself; this is reflected in declining productivity, increasing unemployment and constricted growth of markets. This prompts the agents of financial capital to find various solutions to this problem: as a result, they start to create speculative schemes, invest in not only new markets and lower cost production sites, but also in new technologies and industries. Early risk-taking investors gain high yields from initial investments, leading to generalized but unrealistic profit expectations. In the frenzy phase that follows, massive amounts of capital are directed to emergent industries unable to absorb them. On one hand, these investments enable the creation of new technologies, infrastructures and best practices; on the other hand, they also lead to a speculative bubble and an increasing polarization of rich and poor. When this bubble eventually bursts, a turning point is reached, characterized by serious recession. This, in turn, generates support for state action and regulatory changes that would create a better institutional environment for the new paradigm while avoiding the excesses of financial speculation. Thus begins the synergy phase, a golden age, where production capital with long-term expansion strategies takes the lead. What follows is a period of widespread economic growth and decreasing social inequality. During this period, the paradigm acts as a selection mechanism, favouring certain technologies compatible with its logic and rejecting others. In the maturity phase, the potential of the paradigm gradually becomes exhausted, creating incentives for financial capital to start looking for more profitable investment opportunities and thereby leading the cycle to repeat itself.

Perez (2013) contends that we are now at the turning point of the fifth surge, which will get its full deployment when information and communication technologies are combined with green growth. She argues that the fifth surge, constituted by the ICT revolution and associated techno-economic paradigm, can take the economy in many different directions. However, only if active institutional innovation creates synergies can the surge succeed in bringing another period of stable long-term growth. In her view, this has historically been achieved by government policy. Tilting the playing field to enable and encourage massive green innovation that radically transforms production patterns and lifestyles on a global scale, could do for the world population what the boom after World War II did for the West. It would imply a major overhaul of many products and production methods, a redesign of consumption patterns to stress quality, durability, low-energy consumption, low or no emissions, recyclability and upgradeability. Waste management would be handled as a wealth-creating process, and growth would be decoupled from use of resources (Perez, 2015).

Although Perez is relaxed about the exact timing of the phases, the current surge seems to deviate considerably from the established pattern. If we take 1971 as the starting point of the fifth surge and 60 years as its maximum expected length, then the turning point should have been reached about 15 years ago. The dotcom-boom that occurred around the 2000s would indeed fit this pattern. Since then we should have been enjoying the benefits of the golden age, expecting the maturity phase to begin any time soon. What happened instead, of course, was the global financial crisis and a continued increase in social inequality in various developed countries (Piketty, 2014). The USA, one of the leading countries of the surge, has experienced a further decline in labour's share of national income (Kristal, 2013) and a polarization of the labour market with jobs in the middle range of the skill distribution being squeezed out (Autor and Dorn, 2013).

There are various explanations to why this might be the case. Perez herself (2013, 2015) suggests that the full deployment of the wealth-creating potential of the ICT revolution requires the establishment of adequate socio-institutional and regulatory frameworks at the national as well as international level. According to her argument, this has been missing until now because politicians and policy-makers, blinded by the strong neoliberal ideology, have managed to avoid confronting the task of structural reform. In her view, turning points could last for years and

[3] Perez has occasionally made a reference to techno-economic paradigms as 'meta-routines' (e.g. 2011: 14). We use an alternative notion of a meta-regime in order to distinguish it from other types of rules and rule systems (see Section 3.1 for a conceptual elaboration).

[4] This distinction refers to ways of wealth generation: using money to make more money in the case of financial capital and creating goods and services to make money in the case of production capital (see Perez, 2002: 71–73, for more detail).

**Table 1**
Five Great Surges of Development (Perez 2010: 190, 192–193, 196–197).

| Technological revolution | Core country or countries | New technologies and new or redefined industries | New or redefined infrastructures | Techno-economic paradigm, common-sense innovation principles |
|---|---|---|---|---|
| The Industrial Revolution, 1771[a] | Britain | Mechanized cotton industry<br>Wrought iron<br>Machinery | Canals and waterways<br>Turnpike roads<br>Water power (highly improved water wheels) | Factory production<br>Mechanization<br>Productivity: time keeping and time saving<br>Fluidity of movement (as ideal for machines with water-power and for transport through canals and other waterways)<br>Local networks |
| Age of Steam and Railways,1829 | Britain (spreading to Europe and USA) | Steam engines and machinery (made in iron, fuelled by coal)<br>Iron and coal mining (now playing central role in growth)<br>Railway construction<br>Rolling stock production<br>Steam power for many industries (including textiles) | Railways (use of steam engine)<br>Universal postal service<br>Telegraph (mainly nationally along railway lines)<br>Great ports, great depots and worldwide sailing ships<br>City gas | Economies of agglomeration<br>Industrial cities<br>National markets<br>Power centres with national networks<br>Scale as progress<br>Standard parts: machine-made machines<br>Energy where needed (steam)<br>Interdependent movement (of machines and of means of transport) |
| Age of Steel, Electricity and Heavy Engineering, 1875 | USA and Germany forging ahead and overtaking Britain | Cheap steel (especially Bessemer)<br>Full development of steam engine for steel ships<br>Heavy chemistry and civil engineering<br>Electrical equipment industry<br>Copper and cables<br>Canned and bottled food<br>Paper and packaging | Worldwide shipping in rapid steel steamships (use of Suez canal)<br>Transcontinental railways (use of cheap steel rails and bolts in standard sizes)<br>Great bridges and tunnels<br>Worldwide telegraph<br>Telephone (mainly nationally)<br>Electrical networks (for illumination and industrial use) | Giant structures (steel)<br>Economies of scale of plant: vertical integration<br>Distributed power for industry (electricity)<br>Science as a productive force<br>Worldwide networks and empires (including cartels)<br>Universal standardization<br>Cost accounting for control and efficiency<br>Great scale for world market power: “small” is successful, if local |
| Age of Oil, the Automobile and Mass Production, 1908 | USA (with Germany as vying for world leadership), later spreading to Europe | Mass-produced automobiles<br>Cheap oil and oil fuels<br>Petrochemicals (synthetics)<br>Internal combustion engine for automobiles, transport, tractors, aeroplanes, war tanks and electricity<br>Home electrical appliances<br>Refrigerated and frozen foods | Networks of roads, highways, ports and airports<br>Networks of oil ducts<br>Universal electricity (industry and homes)<br>Worldwide analogue telecommunications (telephone, telex and cablegram), wire and wireless | Mass production/mass markets<br>Economies of scale (product and market volume): horizontal integration<br>Standardization of products<br>Energy intensity (oil-based)<br>Synthetic materials<br>Functional specialization: hierarchical pyramids<br>Centralization: metropolitan centres-suburbanization<br>National powers, world agreements and confrontations |

(*continued on next page*)

**Table 1** (*continued*)

| Technological revolution | Core country or countries | New technologies and new or redefined industries | New or redefined infrastructures | Techno-economic paradigm, common-sense innovation principles |
|---|---|---|---|---|
| Age of Information and Telecommunications, 1971 | USA (spreading to Europe and Asia) | The information revolution<br>Cheap microelectronics<br>Computers, software<br>Telecommunications<br>Control instruments<br>Computer-aided biotechnology and new materials | World digital telecommunications (cable, fibre, optics, radio and satellite)<br>Internet/electronic mail and other e-services<br>Multiple source, flexible use, electricity networks<br>High-speed multi-modal physical transport links (by land, air and water) | Information-intensity (microelectronics-based ICT)<br>Decentralized integration: network structures<br>Knowledge as capital: intangible value added<br>Heterogeneity, diversity, adaptability<br>Segmentation of markets: proliferation of niches<br>Economies of scope and specialization combined with scale<br>Globalization: interaction between the global and the local<br>Inward and outward cooperation: clusters<br>Instant contact and action: instant global communications |

[a] Perez only provides the year for the beginning of each surge.

more than a decade if no major government intervention occurs. This has happened before in the 1930s when governments refused to manage the economic crisis and for a long time failed to recognize the danger of totalitarian systems. Turning points might therefore have several bubbles: we have had two during the fifth surge and might be heading towards another unless governments decide to take adequate action (Perez, 2009). Adopting a global South perspective, Swilling (2013) has argued that we are dealing with a blocked transition resulting from the failure to break the hegemony of globally circulating financial capital and escape the carbon lock-in.

The role of energy technologies is also problematic in relation to dating the surges. Gore (2010) has pointed out that whereas previous surges have been characterized by the exploitation of new energy sources, this did not happen in the installation phase of the ICT paradigm. Again, the literature offers different explanations as to why this might be the case. According to Perez (2013, 2015), the recent development in renewables is driven by ICT deployment (e.g. smart grids) necessary to make the former profitable (Mazzucato and Perez, 2014). Perez's theory predicts that it is at the turning point that the State begins to take action. This is corroborated by the fact that in leading countries of the current surge, especially in China (Mathews and Tan, 2015), politicians and policy-makers have realized that the greening of capitalism is necessary to address the challenges of climate change, including massive reductions in waste and pollution production, and have therefore begun to promote it actively. For Perez, we are thus about to enter the deployment phase of the fifth surge. Swilling (2013) offers a somewhat different perspective: on one hand he points to the success of incumbents in blocking the global energy transition and therefore delaying the green transformation. On the other, he argues that although the fifth, ICT-based deployment is still to come, it will not solve sustainability issues and would therefore require an additional surge, a green-tech revolution.

Indeed both Swilling (2013) and Mathews (2011, 2013) are proposing that we may already be experiencing the incubation or installation phase of the sixth surge. This surge is led by China with India, South Korea, Brazil and Germany also playing an important role. The growing global investment in renewables, exponential in some regions (see Fig. 2), would then be an indication of the frenzy phase of the sixth surge. According to Mathews it is characterized by the following features:

- "A shift to renewables as the dominant energy paradigm.
- Decentralized generation of power, from multiple energy sources.
- Competitive international trade in renewable electric power.
- Reduced energy intensity and enhanced efficiency (e.g. through operations of energy services companies).
- Intelligent (smart) IT-enabled grids for distribution of renewable electric power, giving resilience to power networks.
- Biomimetic organizational and industrial design principles (e.g. linked heat and power).
- Circulation of resources and resource efficiency: circular economy.
- Eco-targeted finance" (2013: 17).

Overall, there is substantial disagreement in the literature about the dating of the recent surge as well as the reasons underlying it. We suggest an alternative interpretation: all these difficulties may imply that the current surge has a markedly different character than the earlier ones, and in fact may represent a transitory period bridging two Deep Transitions.[5] In other words, the turning point of the current surge might simultaneously turn out to be the beginning of a new sequence of

[5] A similar point has been made by the socio-metabolism approach (Haberl et al., 2017: 87–88), suggesting that, because of its fundamentally unsustainable nature, the current socio-metabolic regime of industrial societies should be seen as a transitory stage rather than an end point.

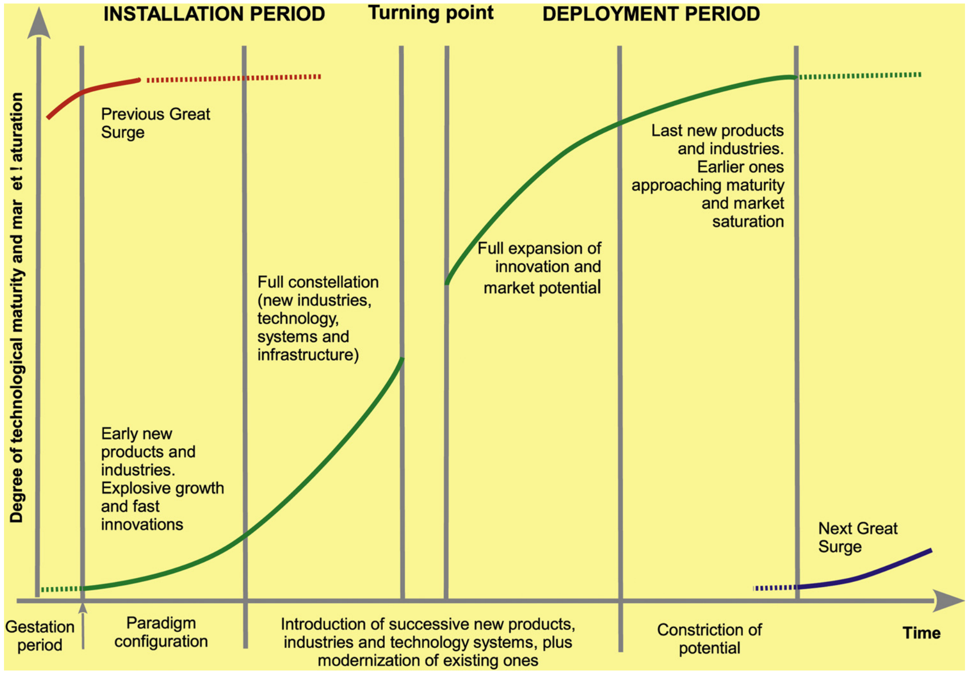


**Fig. 1.** The dynamics of a Great Surge of Development (redrawn from Perez, 2002: 48).

Great Surges of Development, the Second Deep Transition. Formulated this way, the TEP framework helps us to conceptualize the historical unfolding of Deep Transitions in various ways. The techno-economic paradigm can be seen as a coordination mechanism providing both the connections between various socio-technical systems and a shared directionality of their development over time. Moreover, the framework identifies and explains a recurrent long-term evolutionary pattern during which new technological revolutions and associated best practices emerge, become connected and mature in a large number of sectors and geographical contexts. However, whereas the TEP framework stresses major discontinuities between surges, we would suggest that Deep Transitions are constituted by sequences of surges; this implies that, historically, they have accumulated a certain overall directionality. Hence the current events may indicate a transformation on a greater scale and scope than simply another surge.

Although the TEP framework provides an innovative conceptualization of the source of interconnections between socio-technical systems and a build-up of their directionality, its account of the dynamics of socio-technical change remains partial. We see five shortcomings as discussed in detail below.

To begin with, while TEP pays much attention to the actions of the agents of financial and production capital and to the role of governments during the turning point, the contribution of many other social groups, such as scientists, engineers, media, civil society or users in contributing to the dynamics of the surge, is almost completely neglected. This goes against many findings in the history of technology highlighting, for example, how users have considerably shaped the patterns and practices of energy use (Nye, 1998) or transport (McShane, 1994).

Second, although TEP acknowledges the contested nature of new

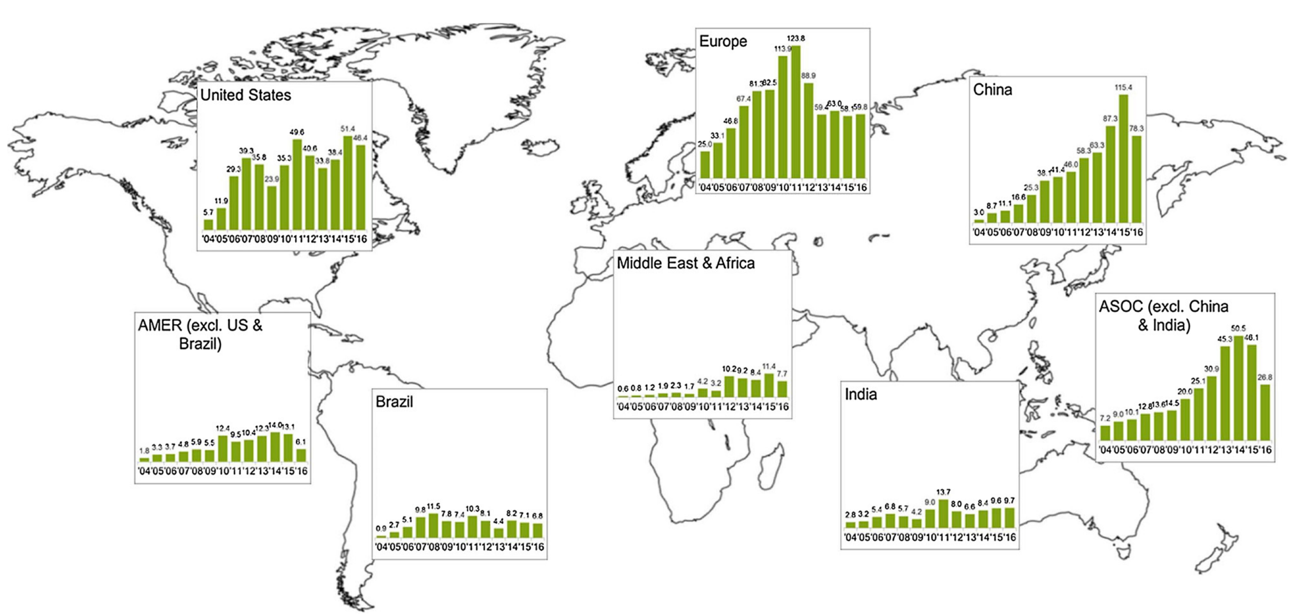


**Fig. 2.** Global new investment in renewable energy by region, 2004–2016 ($BN) (Frankfurt School-UNEP Centre/BNEF, 2017: 22).

paradigms (e.g. Freeman and Louçã, 2001: 157; Perez, 2011: 27), the politics, struggles and conflicts involved are neither explored nor theorized in much detail. As a result, the framework notes the somewhat differing outcomes of various surges (e.g. the relative dominance of the elite during the third surge vs. focus on the welfare for the entire population during the fourth surge), but it does not show how the agency of different groups might actually make a difference for the dynamics within each surge. Moreover, TEP tends to overly focus on the role of the state around the turning point, neglecting the political moves and strategies of various other social groups during different periods. For example, the US mobility system was heavily contested between 1915 and 1930 when the struggle for defining urban space was carried out between pedestrians, traffic engineers, automobile clubs and the industry. By the beginning of the turning point of the fourth surge (1929) the struggle was more or less over, resulting in growing attempts to reshape urban areas to accommodate more cars (Norton, 2008).

Third, the TEP framework seems to be overly state-centred assuming that paradigms emerge in national contexts, in particular in leading countries, and diffuse gradually to other countries. However, this framing tends to exclude various transnational dynamics, for example, the role of international organizations in creating links between socio-technical systems in various countries and standardizing them: something that has been addressed in recent historical literature (Saunier, 2013; Kaiser and Schot, 2014), and sustainability transitions literature (Raven et al., 2012; Sengers and Raven, 2015; Fuenfschilling and Binz, 2017).

Fourth, since the theory provides an endogenous explanation of the surges, it largely neglects the role of exogenous events such as wars. In fact, Perez argues (2002: 160) that while WWI and WWII accounted for specific features of economic development, they neither influenced the nature of surges nor the overall dynamics of their development. They can however accelerate, divert or shape the way a surge is applied (Perez, personal communication, April 2016). Historical evidence, on the other hand, suggests that wars have had a fundamental impact on the directionality of individual socio-technical systems. For example, one could highlight the effect of WWI on the consolidation of the British electricity system (Hughes, 1983). It is hard to see, then, why the same should not hold for interconnected socio-technical systems. According to the analysis of Schot and Rip (2010: 27) WWII was indeed a decisive turning point in the Dutch and, in fact, the European debate on how to modernize, helping to establish the dominance of the idea of modernization through scale increase, mass production and mass consumption. Therefore, we think that the impact of macro-events on the dynamics of surges warrants closer attention.

Fifth, TEP's conceptualization of a paradigm shift does not provide much detail on how the existing paradigm becomes replaced with the new one. As a result, TEP does not pay much attention to the existence of a variety of technological, organizational and institutional innovations in specific niches of application. This largely leads it to neglect the possibility that the decline of one surge might be accompanied by the simultaneous emergence of not only one but many potentially competing embryonic techno-economic paradigms. Moreover, historians of technology have shown that old technologies and practices do not disappear: on the contrary, they remain vitally important, often continue to persist in specific niches of application, compete against newer technologies, and, in certain conditions, might become popular again (Edgerton, 2007). The area of transport provides several examples: the electric vehicle, bicycle and public transportation have time and again resurfaced (and disappeared) as alternatives for the gasoline car (Mom, 2004; Geels et al., 2012; Longhurst, 2015). A similar dynamic might well be at play in the case of techno-economic paradigms. For example, the combination of mass production, mass consumption and resource-intensity was heavily contested during its emergence (Sabel and Zeitlin, 1985; Hounshell, 1985); at no point in time did it dominate all socio-technical systems, even in the USA as a prime example of Fordism (Jessop, 1992; Scranton, 1997), and during the 1980s it became contested again (Piore and Sabel, 1984; Kaplinsky, 2011).

The dynamics between dominant socio-technical systems and niche innovations are at the core of the Multi-level Perspective on socio-technical transitions. It is to this approach that we now turn.

### 2.2. The multi-level perspective

The Multi-level Perspective (Rip and Kemp, 1998; Geels, 2005a; Smith et al., 2010; Grin et al., 2010; Markard et al., 2012) focuses on explaining large scale and long-term shifts – often 50 years or more – from one socio-technical system to another. Examples of transitions include shifts from horse-drawn carriages to automobiles (Geels, 2005b), from manual to mechanized trans-shipment in harbours (Van Driel and Schot, 2005), from mixed farming to intensive pig husbandry (Geels, 2009), and from a fossil fuel-based energy system to one based on renewables (Verbong and Geels, 2007).

The basic components making up the multi-level framework are niches, socio-technical regimes and socio-technical landscape. Regimes can be defined as shared semi-coherent (i.e. relatively stable and aligned) sets of rules or routines directing the behaviour of actors on how to produce, regulate and use technologies part of a specific socio-technical system. These rules are embedded in the various elements of the system – for example, in the case of land-based transportation this includes industry structure, vehicle design, fuel infrastructure, maintenance and distribution network, road and traffic infrastructure, regulations and policies, markets and user practices, culture and symbolic meanings – and they shape innovative activities towards a specific trajectory of incremental innovation (e.g. engineering efforts aimed at increased fuel efficiency, marketing efforts focused on differentiating stable user preferences regarding the features of new automobiles, scientific research for traffic optimization, etc.). MLP's focus is thus on the increasing alignment of sets of rules over time, i.e. the formation of socio-technical regimes that manifest themselves as socio-technical systems.

New rules emerge and gradually become aligned into rule-sets in spaces called niches. These are application areas dominated by specific selection criteria that shield the emerging new and unstable technologies from direct market pressure. Compared to dominant regimes, the actors in niches are few, their interrelations sparse, the focal technology immature and the guiding rules in constant flux. Niche technologies can then be seen as "hopeful monstrosities" (Mokyr, 1990): promising in potential, meagre in performance. For this reason, niches often need to be protected from pressures exerted by the incumbent socio-technical regimes until they have become mature enough to enter the market.

The concept of landscape refers to the exogenous environment shaping both niches and regimes. Landscape pressures involve trends such as globalization, urbanization and climate change, but also events such as wars, natural disasters, and economic crises. This varied set of factors can be combined in a single 'landscape' category because they form an external context that niche and regime actors cannot influence in the short run.

The most important novel insight of MLP is that a transition of a socio-technical system results from the interaction of events on all three levels. A transition comes about through a specific combination and sequence of endogenous and exogenous sources of change, typically proceeding in three phases. In the first, start-up phase, landscape pressure exacerbates the internal problems of the regime creating a window of opportunity for niche technologies. For example, in the second half of the 19th century, increasing urbanization intensified the problems with the horse-drawn carriage regime, including the high cost and low speed of horses or the amount of manure in the streets, facilitating the emergence of niche technologies such as bicycles, trams and automobiles (McShane, 1994; Geels, 2005b). In the second, acceleration phase, niches expand, attract more users, and become mainstream markets starting to compete with the incumbent regime and other niches for dominance. As new technologies diffuse, the accompanying rule-sets are redefined. In the case of urban transport transition, horse-drawn carriages, bicycles, electric trams, stream trams, electric cars, steam cars and gasoline cars all came to compete against each other for decades until the automobile regime finally established itself as dominant (Geels, 2005b). In the third, stabilization phase, the number of actors is high, the technology itself mature and the guiding rules relatively stable, meaning that the former niche has established itself as a new regime. This allows for a sharp increase in adoption as the regime now provides a ready-made 'template' for largely routinized user behaviour. For example, the dominant practices of car use in the USA had been defined by interwar users whereas the post-war adoption, while much more extensive in terms of the number of adopters, was largely based on imitative learning (Kanger and Schot, 2016). It has been shown that, depending on the timing of the interactions between niches, regimes and landscape pressures transitions can occur through various pathways (Geels and Schot, 2007).

The early version of MLP was criticized for downplaying agency, turning insufficient attention to the contested nature of transitions and a failure to capture the influence of specific social groups such as users in shaping transitions (Meadowcroft, 2005; Smith et al., 2005; Smith and Stirling, 2007; Genus and Coles, 2008; Hodson and Marvin, 2010): these issues were taken up in subsequent studies (Van Driel and Schot, 2005; Geels, 2006, 2014; Elzen et al., 2011; Penna and Geels, 2012; Baker et al., 2014; Kanger and Schot, 2016). The resulting additions to MLP have made it clear that the process of transition is far from a moderate and rational consensus-oriented debate about best solutions to clearly defined problems: instead it is rife with struggles between regime-actors and niche-actors with conflicting interests, differing time-scales, problem definitions and perceived best courses of action.

Early MLP studies were also heavily focused on historical transitions in developed countries. Empirically this problem was addressed by shifting attention to developing countries (e.g. Berkhout et al., 2009; Swilling et al., 2016). On the conceptual level, MLP's implicit methodological nationalism (Beck, 2000) – regimes often tended to be studied at the national level, niches at the local or regional level, and landscape at the international or global level – were increasingly challenged by geographers (Coenen et al., 2012; Raven et al., 2012; Hansen and Coenen, 2015; Truffer et al., 2015). For example, Hansen and Coenen (2015) have stressed the role of varieties of capitalism (Hall and Soskice, 2001; Hall and Thelen, 2009) in shaping transition dynamics in a specific territory. The geographical contributions direct attention to the possibility that niches can exist across national borders and regimes can operate in local, national and international spaces. Although some of these insights have already been applied in empirical research (e.g. Chandrashekeran, 2016; Hermans et al., 2016), much more remains to be done to explore the relationships between socio-technical system shifts and geographical contexts on multiple scales.

In the previous section it was argued that in relation to the Deep Transitions perspective, the TEP framework suffers from several shortcomings, including attention to a limited number of actors, limited treatment of the power and politics of surges, state-centredness, lack of attention to exogenous factors and variety in niches. We argue that the MLP vocabulary can complement the TEP framework along these dimensions:

1. The MLP framework includes a richer selection of actors: niches and regimes are shaped not only by the agents of financial and production capital but also by scientists, engineers, policy-makers, users, media, social movements, and so on;
2. As its recent developments show, MLP is somewhat more sensitive to the issues of power and scale of regime shifts. Possibly its emerging insights in these areas can be extended beyond the analysis of individual socio-technical systems;
3. MLP has also started to pay attention to the multi-scalar nature of transitions, including the influence of transnational spaces on knowledge exchange and the alignment of rules across regimes in different spatial locations;
4. Although MLP has been criticized for treating landscape as a residual category (Markard and Truffer, 2008; see a response in Geels, 2011) then compared to TEP, it provides some analytical vocabulary for conceptualizing the impact of macro-trends and events on the evolution of individual socio-technical systems (e.g. the typology of landscape change as developed in Geels and Schot, 2007);
5. MLP also remains much more sensitive to the issue of sustained technological, organizational and institutional variety as preserved in niches. Therefore, in contrast to TEP, which has focused on the 'winning' paradigm, MLP would treat niches as a breeding ground for different and possibly conflicting regimes and techno-economic paradigms.

However, when it comes to its applicability for the study of Deep Transitions, MLP continues to suffer from two important shortcomings: focus on individual socio-technical systems, and lack of attention to how system change is related to broader historical transformations. We will discuss both.

A large majority of MLP has focused on transitions involving individual socio-technical systems. In comparison, only a few studies have explicitly explored interactions between multiple regimes and systems. Geels (2007) found that the changing relationship between radio and recording regimes – from competitive to symbiotic – contributed to the rise of a music style that can be interpreted as a new combined regime (rock and roll). Raven and Verbong (2009) added two other types of interaction, integration and spill-over. Papachristos et al. (2013) argued that multi-regime interactions (disruptive or reinforcing) might influence the niche formation process through enabling niche transfer, interference or the emergence of a new niche.

While all the above focused on the possible outcomes of multi-regime interaction, recent work (Konrad et al., 2008; Bergek et al., 2015) has also suggested two ways in which these connections are established: functional and structural couplings. The former refer to input-output relationships, such as supplier-buyer relationships or global value chains. Structural couplings refer to shared use of infrastructures, actors and rules: for example, telecommunication firms using electricity cables of utilities or both types of companies using the same R&D organization. These findings imply that it is through these couplings that *ad-hoc* multi-regime dynamics become gradually consolidated and eventually stabilized. Again, it is important to stress that these couplings do not respect national borders but operate within their own geographical space. Here we would draw special attention to the role of international and transnational organizations that are responsible for developing standards, facilitating mutual learning, providing training and development, aggregating the lessons learned in different countries, and acting as international intermediaries (Kaiser and Schot, 2014). As such they constitute an important transfer mechanism between states and nationally bounded organizations, as well as an arena for discussing and negotiating the directionality of transitions. The study of these international and transnational actors can therefore help to explain how regimes diffuse from one system to another and develop a specific spatial reach.

The second shortcoming is shared by MLP and TEP. Namely, although both have acknowledged that socio-technical systems may exhibit wider societal and global impacts (e.g. Geels, 2005a: 93; Perez, 2013: 11) neither have generally pursued this avenue in empirical research. As a result, the ways in which particular systems and complexes of systems become linked to macro-level changes have remained undertheorized. While this omission is not particularly important from the perspective of MLP and TEP since both are focused on explaining regime/meta-regime shifts, it becomes significant from the Deep Transitions viewpoint. This is because Deep Transitions are built up through successive surges: therefore, the conceptualization of connections between transitions and surges, as well as the interaction of different surges, forms part of our overall analytical framework. Here we

**Table 2**
TEP and MLP in comparison.

| | TEP | MLP |
|---|---|---|
| Unit of analysis | Techno-economic paradigms of interconnected systems | Socio-technical regimes (aligned rule-sets) of individual systems |
| Temporal scale | 40–60 year long cycles | 50+ year long transitions |
| What is explained? | Paradigm shift | Shifts to new socio-technical systems |
| In terms of what? | Actions of the agents of financial and production capital, state intervention around the turning point | Interaction between incumbent socio-technical regimes, emerging niches (both including a wide range of different types of actors) and exogenous landscape pressures |
| Conflict and contestation | Conflict and contestation is acknowledged (especially around the turning point) but not theorized in detail | Emerging attempts to theorize the conflict and contestation of transitions |
| Geographical scale and diffusion | New paradigms gradually diffuse from the core towards more peripheral regions and countries | Increasing sensitivity to the multi-scalar nature of transitions |
| The role of exogenous events | The societal shaping of paradigms is occasionally recognized (e.g. Freeman and Louçã, 2001) but is not an integral part of the framework | Integral part of the framework (landscape events decisively shape niche and regime dynamics) |
| Replacement and sources of variety | Not much attention is turned to specific processes by which one paradigm replaces another, largely leading to the neglect of a variety of alternative directions | Continuous variety that emerges from, and is sustained in, niches before and after specific transitions is an integral part of the framework |
| Impact on the wider environment | Impacts of surges on economy and society are acknowledged but not theorized | Impacts of mature regimes on landscape are acknowledged but not theorized |

make the first attempt to provide an analytical vocabulary for between-surge connections. For this purpose we draw on the dual meaning of the notion of landscape as deployed by MLP that enables us to distinguish between two mechanisms of system-landscape interaction.

Following Geels and Schot (2007), who introduced the typology of landscape change, later MLP studies have often treated landscape as a collection of various macro-trends or macro-events (e.g. individualization, climate change). This processual view provides one way of thinking about system-landscape links: seeing the specific mode of operation of socio-technical systems/complexes of systems (itself the manifestation of regimes/meta-regimes), leading to certain outcomes that partially contribute to some broader landscape trends. Examples include the transport regime based on individualized automobility that, over the course of the 20th century, has played an important part in contributing to resource depletion and greenhouse gas emission. Another example is the meta-regime of mass consumption that, also during the 20th century, strongly shaped and reinforced individualization. As a result, many alternatives, such as collective mobility, energy, housing, washing and cooking practices were abandoned (Schot et al., 2010). We call this type of interaction the feed-in mechanism to reflect its contribution to landscape dynamics.

However, the original definition of landscape indicates a rather different sense of the concept: "The sociotechnical landscape is a landscape in the literal sense, something around us that we can travel through, and in a metaphorical sense, something that we are part of, that sustains us" (Rip and Kemp, 1998: 334). This view, echoed by analyses of many historians of technology (e.g. Edwards, 2003; Van der Vleuten, 2004; Edgerton, 2007), sees landscape as a structure, expressed in infrastructures: a taken-for-granted and largely invisible backdrop of daily life. During the First Deep Transition, this infrastructure has become a 'technotope' (integrating nature into it). This infrastructure consists of a layered web of mature socio-technical systems that does not contribute to landscape dynamics: instead it constitutes the landscape. Therefore, the emergence of new socio-technical systems can be seen as a process through which yet another layer becomes added to the socio-technical landscape without removing those already present. These landscape layers, in turn, start to structure further interactions between niches, regimes and meta-regimes (e.g. the reliance of the digital revolution on electricity networks). We call this type of interaction the sedimentation mechanism to refer to its contribution to landscape as a structuring environment.

Table 2 summarizes the foregoing discussion, highlighting the similarities and differences between the two approaches.

## 3. Towards a conceptual framework of Deep Transitions: combining TEP and MLP

In this section we focus on the connections between transitions and surges, thereby sketching the prospective outline of the Deep Transitions framework. Since the notion of rules occupies an important place in the theoretical edifice, we begin with a formal definition and a distinction between rules, meta-rules, regimes and meta-regimes. Subsequently, we provide an overview of the conceptual vocabulary of the Deep Transitions framework. Drawing on the above discussion of TEP and MLP, including some conceptual extensions, we then combine the strengths of both frameworks to provide a multi-level explanation of great surges of development, formulating eight propositions on the overall patterns and mechanisms of the process.[6]

### 3.1. *The conceptual vocabulary of Deep Transitions*

Central to the Deep Transition framework are the interrelated dynamics of actors, rules and socio-technical systems. As with MLP, the framework brings together insights from Science, Technology and Innovation Studies, evolutionary theory, sociological structuration theory and institutional theory (see Geels and Schot, 2010: 29–52, for a general argument on MLP; see Fuenfschilling and Truffer, 2014, for further conceptualization of the institutionalization process in transitions theory). In particular, our framework has a good fit with evolutionary institutionalism in which rules operate as genes, and where the overall dynamics can be captured by the notion of variety, selection and retention (Fürstenberg, 2016). Rules can therefore be seen as the retention mechanism (genotype) while systems can be seen as the expression of rules that may come in many variants (phenotype) (Blyth et al., 2011; Lustick, 2011). One important thing to note is that, through the focus on socio-technical systems, both the sustainability transitions work as well as the Deep Transition theory add a largely unexplored material dimension to institutional theory (Onsongo, 2016).

The notion of rules occupies a central place in institutional theory including its evolutionary variant. In the Deep Transition framework, drawing on North (1990: 3), rules are defined as humanly devised constraints that structure human action, leading to regular patterns of practice. In line with sociological thinking (Giddens, 1984; Sewell, 1992), rules are also seen as setting constraints on certain actions while making other actions possible (e.g. the standardization of communication protocols enabling the widespread use of the Internet). An

[6] Note that these mechanisms derive from the literature review. Further work is likely to uncover additional mechanisms connecting transitions in single systems to great surges of development.

important quality of rules is their generalizability or transposability (Sewell, 1992: 7–8), meaning that they can be used in a variety of contexts. Note that this definition is very minimal: according to this definition, rules can be implicit or explicit, informal or formal, descriptive (unsanctioned) or injunctive (sanctioned) (Cialdini et al., 1990), subject to differing interpretations, etc.

Central to our framework is the recognition that rules differ along the dimensions of scope (present in single or multiple systems) and systemicity (single rules or rule-sets). Hence we distinguish between rules (single rule in a single system), meta-rules (single rule in multiple systems), regimes (rule-set in a single system) and meta-regimes (rule-set in multiple systems). Examples of each include.

1. The drive to optimize fuel efficiency (rule in the automobility system).
2. An imperative to use fossil fuels (a meta-rule present in many systems such as agriculture, energy provision or mobility).
3. Fordist mass production at the beginning of the 20th century (a regime characterizing the automobility system).
4. Global mass production after WWII (a meta-regime characterizing multiple socio-technical systems).

A Deep Transition can therefore be seen as a process by which some rules emerge, come to be aligned to each other and diffuse to various systems, thereby obtaining differing degrees of scope and durability.

However, sociological thinking also includes the notion of resources and the idea that structures are seen as combinations of rules and resources (Giddens, 1984: 377). The exact relationship between rules, resources and structures has remained unclear in much of the transition literature. Elaborating on Giddens's work, Sewell (1992) argues that resources consist of human and non-human elements. Structures then have a dual character, being defined simultaneously by rules, which are virtual, and resources, which are actual (Sewell, 1992: 10–13). In the Deep Transitions framework this translates into rules (genotype) that are expressed or embedded in socio-technical systems (phenotype). The combination of rules and resources, in turn, manifests itself in recurrent patterns of practice (e.g. the trajectory towards incremental innovation in mature systems). However, it must be stressed that the relationship between rules and systems is not that of one-way deterministic influence: ongoing technological experimentation by niche and regime actors can lead to the introduction of new rules or to the modification of existing ones (e.g. the current impact of ICTs on privacy legislation). In our framework, therefore, rules and socio-technical systems are seen as mutually constitutive.

We are now in a position to present the unified framework of Deep Transitions. For this purpose we aim to use a common language transcending the differences between TEP and MLP. Therefore, Table 3 provides a summary of the basic concepts to be used in the following account, including a brief formal definition, the place of these concepts in the framework, and an empirical example.

### 3.2. The dynamics of Deep Transitions

Based on the introduced vocabulary and basic concepts, we will formulate a number of propositions on the patterns and mechanisms relating to the emergence, acceleration, stabilization and directionality of Deep Transitions.

The first proposition is that different surges begin with the parallel emergence of new socio-technical systems and associated rules in several niches in parallel without much coordination. As landscape pressures destabilize various dominant and established regimes, multiple windows of opportunity are created for niches containing the promise of new regimes. Some of these rules become aligned (begin to form a regime) and break through, resulting in regime-shifts in individual socio-technical systems. These regime destabilization and niche formation processes are influenced by a host of actors, such as firms, investors, governments, social movements and users, occurring in various geographical contexts (including transnational spaces connecting different parts of various nation-states), at variable speeds and with variable outcomes. The success of some regions or countries can be explained by their ability to learn from the experiments conducted elsewhere (e.g. by participating in transnational and international platforms and organizations), to 'borrow' the outcomes (e.g. new technologies, organizational innovations, institutional lessons) and to bring them together in a particular manner. In any case, all these niches and emerging regimes provide a raw material, an essential variety from which more expansive meta-regimes and eventually one dominant meta-regime will be constructed.

The second proposition is that during the irruption phase the emerging and incumbent rules and regimes come to compete against each other in individual systems, resulting in transitions (or transition failures) – outcomes that can be analysed in conventional MLP terms. Deep conflicts might develop between regime and niche actors, and between actors promoting different niche-innovations. Early interactions between some regimes might occur and some rules may turn into meta-rules as a result. However, overall these interactions, as well as their outcomes, remain *ad hoc*, non-standardized and accidental in nature: at this point no systemic connections between regimes and systems are created, and therefore no clear directionality is established. The high degree of uncertainty means that, in many ways, the shape of the eventually prevailing socio-technical systems and their contribution to broader societal processes is virtually impossible to determine at this point.

The third proposition is that towards the end of the irruption and the beginning of the frenzy phase, many rules increasingly start to cross the boundaries of a single system, thereby becoming meta-rules, and partially align to each other. In a similar way to the irruption phase, however, this acceleration process continues to be contested by different stakeholders with differing interests and power resources to influence the debates as technological standards are never neutral (Abbate, 1999: 147–180; Bowker and Star, 2000). In this way, different rules of various socio-technical systems become linked and connections between them gradually start to become consolidated. At this point, however, several possible competing meta-rules still exist; it therefore remains unclear which ones would eventually prevail.

The fourth proposition is that two mechanisms for achieving more coordination across the boundaries of a single system are structural and functional couplings. For example, a waste management system provides an input into the energy system (functional coupling) and both systems begin to share a R&D facility (structural coupling). These couplings lead to mutually oriented activities of a wide range of actors involved in these systems, including firms, investors, users, social movements, civic groups, cities and various government agencies.

The fifth proposition is that an additional mechanism, further facilitating and accelerating the creation of between-system links, is the aggregation and intermediation work of inter- and transnational organizations. These actors bring together experiences and ideas from different sectors, nurture mutual learning processes, help to establish networks between various stakeholders, and shape expectations about the future of the niches. The nature of these activities is markedly different from the dynamics of the irruption phase: instead of largely uncoordinated interactions, the aggregation work performed in the frenzy phase is much more purposeful, geared towards homogenization and standardization.

The sixth proposition is that the competition between meta-rules and the emergence of partially aligned rule-sets is finally resolved at the turning point. Until then there is still a variety of possible meta-regimes, and therefore many possible directions in which the new surge might unfold. The combined pressure of endogenous and exogenous crises – the bursting of a speculative bubble around new technologies and nascent industries, and the occurrence of a rapid shock (such as war), or an accumulation of a longer trend reaching a critical threshold (such as

**Table 3**
Overview of basic concepts used in the framework.

| Concept | General definition | Place in the framework | Example |
|---|---|---|---|
| Niche | Spaces for radical innovation that are protected by specific selection criteria | Sustained sources of variety for innovations; seeds for rules and meta-rules | Meat-packing industry niche as one of the precursors for mass production |
| Regime | Semi-coherent rule-sets directing the behaviour of a set of actors in a single socio-technical system | Genotypes of socio-technical systems | Fordist mass production as defined in the automobile industry at the beginning of the 20th century |
| Socio-technical system | Configuration of actors, technologies and institutions for fulfilling a certain societal function | Manifestation of regimes (phenotype) that may differ depending on the specific characteristics of the environment | A system of individual passenger transport in the post-war USA |
| Meta-regime | Semi-coherent rule-sets directing the behaviour of a set of actors in multiple socio-technical systems | Genotypes of complexes of socio-technical systems | The general logic of mass production as employed by various industries after World War II |
| Complexes of systems | Configurations of socio-technical systems | Manifestations of meta-regimes (phenotype) that may differ depending on the specific characteristics of the environment | The mutual dependence of the automobile system and the construction industry in the interwar era |
| Great surge of development | The process of diffusion and societal assimilation of meta-regimes | Successive surges constitute Deep Transitions | The Age of Oil, the Automobile and Mass Production (Perez, 2010) |
| Landscape | A set of macro-structures and dynamics | Exogenous structures and trends that shape the interactions between niches, regimes and meta-regimes in the short term, and are partly shaped by them in the long term | The amplifying effect of mass production on individualization, leading to the abandoning of collective mobility and energy practices during the 20th century (Schot et al., 2010) |
| Deep Transition | Series of connected and sustained fundamental transformations of a wide range of socio-technical systems in a similar direction | The First Deep Transition has fed the double challenge of environmental degradation and social inequality: the Second Deep Transition might emerge as a response to this challenge | The unfolding of five successive surges over the last 200–250 years |

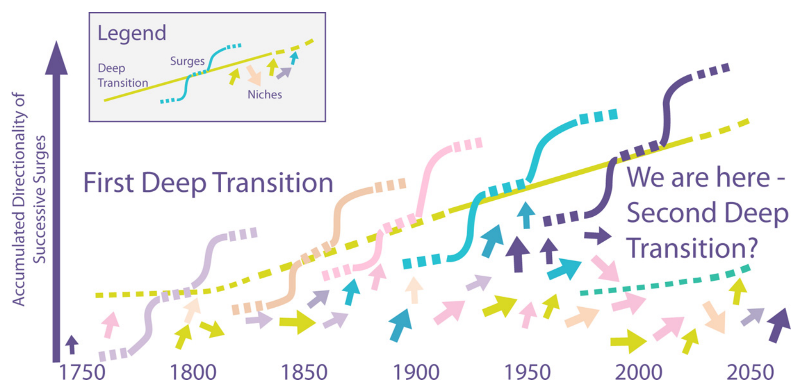


**Fig. 3.** Long Term Continuity in Deep Transition Dynamics.

climate change) – provides an impetus for powerful actors to tilt the playing field decisively towards a set of specific meta-rules and the alignment of these into a specific meta-regime driving out the competitors. Therefore, from this point onwards one can start talking about the existence of *the* dominant meta-regime advanced by leading countries and providing directionality across many socio-technical systems. Other countries then feel forced to play a catch-up game. However, the alternatives do not disappear entirely: they may remain regime-specific victories or revert to niche status, waiting to re-emerge at the next suitable opportunity. These spaces represent alternative pathways advanced at specific locations, in specific systems and by dedicated countries (Fig. 3).

The seventh proposition is that during the synergy phase the dominant meta-regime starts to exert its influence in three directions. In relation to niches it acts as a selection mechanism, favouring technologies compatible with its logic and rejecting non-compatible ones (Perez, 2011: 20). It continues to diffuse from one system to another, leading to the increasing take-up of its principles in various systems and therefore to ever stronger couplings between different regimes. Finally, through the feed-in mechanism, the manifestations of the dominant meta-regime start to contribute to broader landscape trends, resulting in many unforeseen and unintended consequences.

The eighth proposition is that as the maturity phase proceeds, new problems start to appear that cannot be fully resolved within the confines of the dominant meta-regime. The scene is then set for yet another surge, with new systems becoming the main loci of radical innovative activities. But this loss in visibility and direct impact does not mean that the mature meta-regime loses its impact altogether. On the contrary, through the sedimentation mechanism the manifestations of the surge have become firmly embedded in the socio-material fabric of society, expressed in infrastructures, spatial patterns of urbanization or vast webs of routine everyday practices. This layer of the landscape provides the context in which new niches, regimes and meta-regimes can emerge, interact and flourish. Combined with the feed-in mechanism, the overall result is that the surge continues to shape the landscape long after it has ceased to be the hotspot of radical innovative activities and major source of economic growth.

The whole sequence and the set of propositions are summarized in Fig. 4.

## 4. Discussion: an outline of a Deep Transitions research agenda

We realize the tentative nature of the ideas presented here. Rather than a fully-fledged theory, the proposed Deep Transitions framework should be read as an extended adventurous set of propositions. This implies that we hold many elements of our framework, including its foundational assumptions, open to criticism and modification. However, we would like to anticipate two common misunderstandings

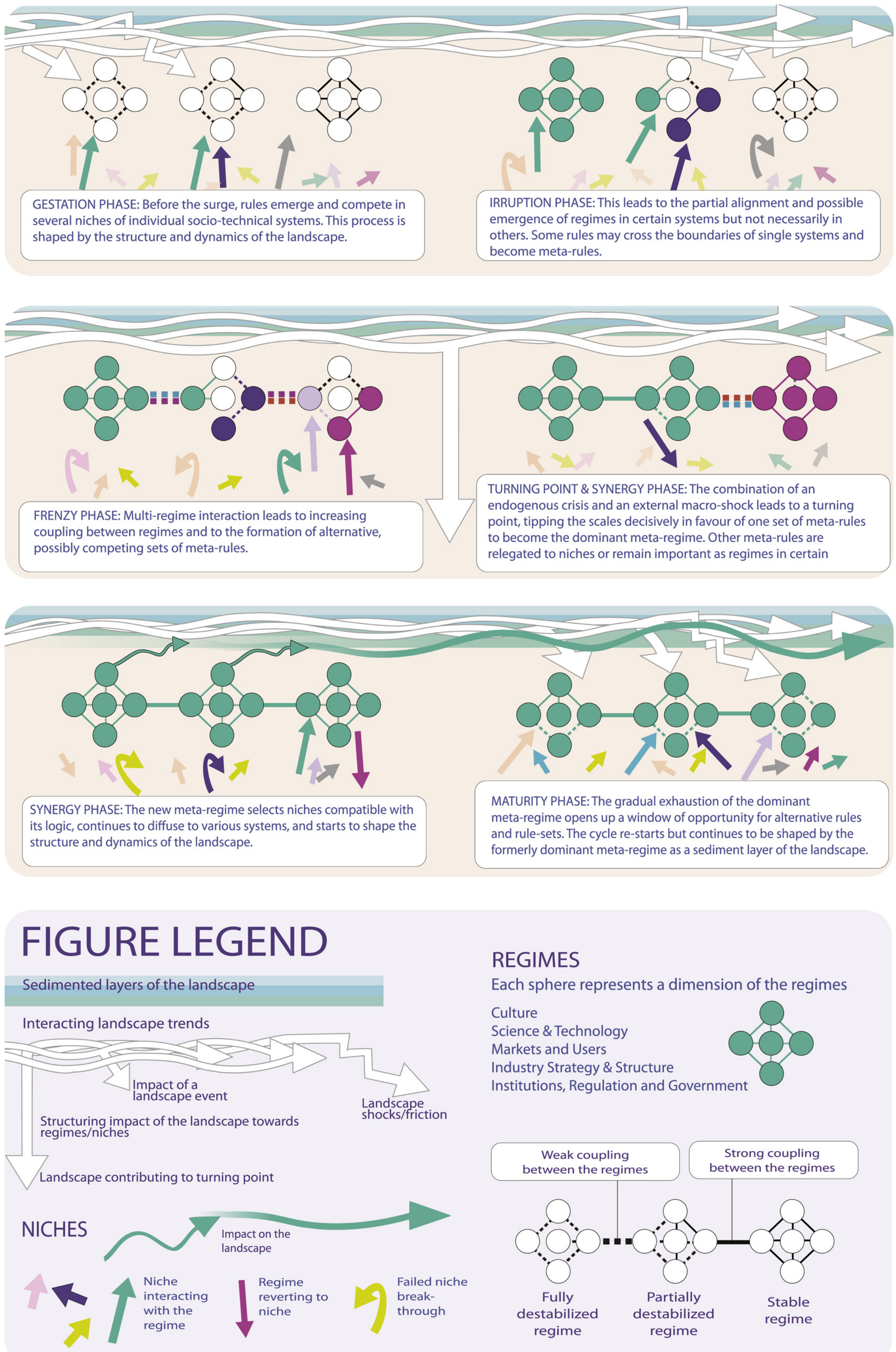


**Fig. 4.** The multi-level explanation of a great surge of development.

we have encountered while developing, discussing and refining this paper. Many have worried that the approach presented here is teleological and promotes an overly structural explanation, leaving little room for agency. We would like to explicitly stress the contrary: neither the First nor the Second Deep Transition were or are bound to progress towards a pre-defined end-state. We are merely sceptical that the problems created by the First Deep Transition can eventually be solved within the bounds of this transition. This results in our claim that niches emerging in response to the persistent problems generated by the First Deep Transition may lead to the Second Deep Transition, undermining the very principles of production, distribution and consumption on which the First Deep Transition is based. But as an historical possibility, the Second Deep Transition can happen in different ways with a range of outcomes, the agency of various actors crucially shaping the process. There is, therefore, no guarantee that current developments would necessarily lead to the reduction of inequality or address climate change in a way many would recognize as sustainable development.

The Deep Transition framework requires further conceptual development; but first and foremost it needs empirical testing. We therefore end the paper with the contours of a possible research strategy, and finally a reference to the need for additional conceptual work in order to endogenize the notion of socio-technical landscape and complement the Deep Transitions framework.

In existing MLP and TEP literatures, attempts to identify patterns in the development of socio-technical systems have often been made on the basis of qualitative interpretation of historical and contemporary data. While this has led to the creation of compelling, historically-informed, nuanced and analytically fruitful narratives of individual system transitions, it may not be a viable option for the study of the long-term evolution of multiple systems containing many niches. This is why we advocate the employment of a mixed method approach that combines quantitative longitudinal mapping of socio-technical systems change, using, for example, different bibliometric techniques, and qualitative case studies that zoom in on critical moments and developments.

To explore the plausibility of the key propositions we propose that the research strategy should not focus on the development of systems in all its variations, but on the development of rules, regimes, meta-rules and meta-regimes as the main unit of analysis. This presents an additional issue since the transitions, and for that matter institutionalization literature, have largely failed to operationalize rules. There are not many quantitative studies of rules available.[7] However, a rigorous empirical test might include a quantitative mapping of general patterns of the emergence, acceleration, stabilization and directionality evolution of rules, meta-rules, regimes and meta-regimes. We suggest that this can be done through the analysis of textual data extracted from news articles and professional trade journals using a variety of Natural Language Processing techniques such as topic modelling (Blei and Lafferty, 2007; Blei et al., 2003; Crain et al., 2012) and co-word analysis mapping (Callon et al., 1991; Furukawa et al., 2015). These techniques can be used to generate clusters of keywords representing rules (generated with the help of historical experts of the socio-technical systems studied). The change in these keyword clusters can be treated as an indication of the evolutionary dynamics of meta-rules and meta-regimes.

The case study research could focus on identifying and analysing Deep Transition controversies. This could involve conducting an in-depth qualitative exploration of debates surrounding various competing meta-rules and meta-regimes, the role of inter- and transnational organizations (ITOs) in establishing couplings between meta-regimes, and the role of wars as selection mechanisms in stabilizing meta-regimes. Examples of controversies, which have been discussed throughout the First Deep Transition and will also shape the possible unfolding of the Second Deep Transition, are mass-production for global markets vs. socially useful and craft-based production for local markets, linear resource-intensive economy based on the use of fossil fuels vs. circular waste-free economy based on the use of organic materials, and individual vs. collective consumption.

Methodologically, the focus on controversies is revealing for a number of reasons: it is during these moments that rules, meta-rules, regimes and meta-regimes, otherwise embedded in socio-technical systems and difficult to detect, are being questioned and made visible. The same applies to alternatives that (re-)emerge during controversies. Finally, this strategy also allows for an analysis of political conflict and the agency involved in Deep Transition developments, the identification of stakeholders promoting, subverting and challenging specific ideas.

Deep Transitions research is not only about the past but also about the future. Further methodological work is needed on how qualitative socio-technical scenarios and quantitative modelling (Foxon, 2013; McDowall, 2014) can be combined to probe the possible futures related to the Second Deep Transition. Looking ahead up to 2050, and aiming to capture at least two surges, these efforts might focus on the articulation of niches in which new competing meta-regimes might emerge, on multi-regime dynamics, crises and shocks through which these meta-regimes might evolve and come to compete, and on processes by which successful meta-regimes might diffuse and gain dominance in a wider variety of socio-technical systems. These scenarios could also explore transnational dynamics or examine how competing meta-regimes may be adopted in different regions across the world, thereby avoiding a Western bias.

In this paper we have combined the insights of TEP and MLP to provide a more comprehensive explanation of surges. Although this has brought us closer to understanding the overall dynamics of Deep Transitions, we argue that one additional step is needed. This is an exploration of long-term continuities of the industrial society extending beyond a single surge. Here we can draw on the insights of a diverse body of works that have addressed the twin processes of industrialization and modernization (Harvey, 1990; Mokyr, 1990; Giddens, 1991; Beck, 1992; Latour, 1993; Grübler, 2003; Misa et al., 2003; McNeill and McNeill, 2003; Arthur, 2009; Lamba, 2010; McClellan and Dorn, 2015; Moore, 2015) to identify the characteristic rules, resources and practices of industrial modernity. Conceptually such a study would allow a further unpacking of the notion of the socio-technical landscape, seeing industrial modernity as a broad selection environment that, on one hand, is built up through the surges but which, on the other hand, shapes the interaction of niches, regimes and meta-regimes. After all, it is the very notion of between-surge continuity that makes it meaningful to speak about the last 200–250 years as an unfolding of a single process – what we have called the First Deep Transition.

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[7] Exceptions in the transitions literature are Fuenfschilling and Truffer (2014, 2016) and Onsongo (2016).

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